Study of electromagnetic radiation pollution in an Indian city

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Abstract Electromagnetic radiation emitted by cell phone towers is a form of environmental pollution and is a new health hazard, especially to children and patients. The present studies were taken to estimate the microwave/RF pollution by measuring radiation power densities near schools and hospitals of Chandigarh city in India. The cell phone radiations were measured using a handheld portable power density meter TES 593 and specific absorption rates were estimated from the measured values. These values of electromagnetic radiation in the environment were compared with the levels at which biological system of humans and animals starts getting affected. The values were also compared with the international exposure limits set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The highest measured power density was 11.48 mW/m^2 which is 1,148% of the biological limit. The results indicated that the exposure levels in the city were below the ICNIRP limit, but much above the biological limit.

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Introduction

A new kind of pollution coming from electromagnetic radiation referred to as "dirty electricity" has increased many times in the last 30 years. This has generated concern on the health and safety issues regarding its effect on humans and animals. Studies by various research groups suggest that some biological changes possibly occur in animals and birds due to exposure to RF radiation (Harst et al. 2006; Everaert and Bauwens 2007; Balmori and Hallberg 2007; Balmori 2009, 2010). For example, cell phone radiation is one of the many factors being speculated which are responsible for collapse of honeybee colonies and decreasing population of house sparrows, however the exact cause remains ambiguous with the little data available. It could be a single factor or a combination of different factors like temperatures, droughts, pesticides, and viruses which cannot be ruled out. However, this has led to a recent increase in public concern over the effect of electromagnetic/cell phone radiation on humans.

The short-term effects of these radiations, as suggested through field studies on people living within 300 m of cell phone tower, could be sleep disturbance, depression, headache, nausea, visual disorders, respiratory problems, nervousness, and agitation (Santini et al. 2002). But these symptoms may be an indication of many other possible causes as well. At the moment, it is hard to comment on the chronic effect of these radiations, as these are not the

established facts yet; however, it is reported by some research groups that slow long-term exposure may cause cancer, brain tumors, and DNA damage (Dolk et al. 1997; Stagg et al. 1997; Marinelli et al. 2004; Hardell and Carlberg 2009).

In view of the possible harmful effects of microwave/RF radiation on the biological systems, which are based on the studies reflecting various parameters, e.g., dose–response characteristics, time-varying features, thermal and nonthermal effects (Santini et al. 2002), regulatory boards, such as the World Health Organization, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the Institute of Electric and Electronic Engineers, and the Federal Communications Commission have published guidelines on the levels of the RF exposure. Some laboratory studies indicate that the biological effects can occur at power density levels as low as 0.01 to 1 mW/m^2 above which exposure should be considered as of concern. However, there is a discrepancy between the recommended limits and the levels at which biological changes start taking place.

It is a known fact that power density levels of radiation decrease with increase in distance. Hence if a tower is closer to a place, e.g., at 100 m from a school, the dangers are much more than a school which is situated at more than 1,000 m. Since, this distance law holds good only if the antenna is in direct line of site, but in actual case, the radiation can be obstructed by metal objects, cement walls, or many other factors. It also depends upon the orientation of the antenna. The locations facing the tower antenna will have more radiation as compared to the one on the back side of it. Thus, the distance measurement from the tower cannot be said to be a reliable method to grade a place as safe or unsafe. The more accurate method will be to measure the actual power density levels at the area of interest to get the values of radiation exposure.

With the above background and in view of the vulnerability of young children and patients to these radiations, the aim of the present field study was the collection of radiation power density data around schools and hospitals, statistical evaluation, and exposure assessment of electromagnetic radiations coming from cellular phone towers in the city of Chandigarh, India. The objective is to get quantitative information about the actual power density levels

coming from cell phone towers to know how safe our cities are from the electromagnetic radiations. The city was chosen for this survey as it has many prominent and prestigious medical institutes and schools of the region. Chandigarh is a city with population of 900,000 and an area of 114 km^2.

Materials and methods

Two parameters which are mainly used to express radiation exposure levels are power density and specific absorption rate (SAR). Power density measurements were performed using a handheld portable power density measuring TES 593 electrosmog meter from TES Electrical Electronic Corp. The measuring device covered wide range of frequencies from 10 MHz to 8 GHz. The instrument was sensitive enough to detect fields as low as 0.0001 mW/m^2. It has the triple axis sensor which gave the accurate three-dimensional measurements without having to point the antenna in a particular direction. The readings were allowed to stabilize for 2 to 3 min before noting them in the "maximum average" mode. The measurements from three different spots around the area of interest were then averaged. The measuring device was kept at a height of 5 ft from the ground level as this is the average height within which most children are exposed. The power density measurements are given in milliwatts per square meter. The measurements included a total of 62 locations with 50 schools and 12 hospitals of Chandigarh and surrounding localities.

The rate at which radiation is absorbed by the human body is measured in terms of SAR. It is described as the transfer of energy from electric and magnetic fields to charged particles in an absorber. In this work, local SAR has been estimated at a point on the brain as the absorber. Local SAR is related to electric field through the equation (Ghandi 1990; Guy and Chow 1986):

$$\mathrm{SAR} = \sigma |E^2|/\rho_{\mathrm{m}} = P_{\mathrm{A}}/\rho_{\mathrm{m}} \qquad (1)$$

where

$P_{\mathrm{A}} = \sigma\,|E^2|$	Absorbed power density by the human brain tissue
$|E^2|$	Magnitude of electric field vector
σ	Conductivity of the human brain tissue
ρ_{m}	Mass density of the human brain tissue

The measuring electrosmog meter showed power density values in both milliwatts per square meter and volts per meter units. These values were used to estimate SAR using Eq. 1. Conductivity and mass density values were taken from Table 1 for frequencies 900 and 1,800 MHz. The SAR values estimated using Eq. 1 are presented in Table 3.

Results

In the present survey, the level of radiation was observed to be above the biologically safe exposure limits (less than 1 mW/m^2) in 22 schools out of 50. The power density values of unsafe schools ranged from 1 to 11 mW/m^2. The data are shown in Fig. 1 in the form of a bar diagram. The schools and hospitals which were having higher values of radiation were within 400 m distance from the tower. Out of the hospitals surveyed, six of them were found to have radiation exposure levels above biological limit. A major hospital and research center in the city showed RF radiation levels as high as 7.7 mW/m^2 (Fig. 1). However, all the schools and hospitals were observed to have radiation levels much below the one recommended by ICNIRP as shown in Tables 3 and 4. The findings showed higher exposure levels in the evening hours compared to noon hours. The evening exposure levels went up to 14 mW/m^2 as compared to 9 mW/m^2 at noon or afternoon hours for the same location.

Discussion

Many countries have taken the precautionary measures to protect the public from the radiation, but the recommended safety limits vary from country to country. The criterion of safe limit chosen in the present
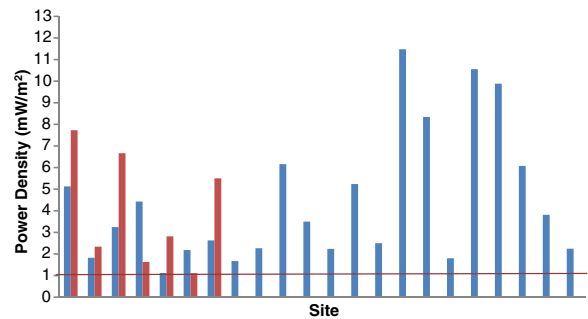

Fig. 1 Bar representation of radiation levels in overexposed schools (*blue*) and hospitals (*red*). The *red horizontal line* is the reference levels adopted in the present study which corresponds to 1 mW/m^2 of power density above which the exposure to microwave radiation results in biological malfunctioning. Twenty-two schools and six hospitals showed radiation levels above 1 mW/m^2. The highest measured power density value was 11 mW/m^2 which is 1,148% of the biological limit but only 0.26% and 0.13% of the ICNIRP limit for 900 and 1,800 MHz, respectively

study is the one recommended in the scientific literature above which biological effects start showing (Wolke et al. 1996) and the one adopted in Salzburg, Austria (1 mW/m^2). The current safety limits in India (600 mW/m^2) and some other countries are by many orders higher than the values at which biological effects of electromagnetic radiations are reported in the literature (Table 2).

As is evident in Table 2, the radio sickness starts at levels as low as 0.02 mW/m^2. The table does not show the effects of very high radiation doses which are much more severe. In terms of SAR, harmful biological effects which start occurring in brain are reported to be at SAR as low as 0.001 W/kg where an increase in molecular stress response in cells occurs (de Pomerai et al. 2000). Change in calcium concentration in the heart muscle cells of guinea pigs have been noticed at the same SAR values (Wolke et al. 1996). Increase in permeability of the blood–brain barrier (BBB) in mice has been observed at SAR levels of 0.008 W/kg (Persson et al. 1997). BBB is a selective barrier, which allows transport of the indispensable nourishing elements such as glucose towards the brain, but blocks the potentially harmful substances for nerve cells. Exposure of rats to 900 MHz radiation of SAR from 0.016 to 5 W/kg showed a leak of albumin in BBB (Salford et al. 1994).

Hence, if we take into account the values of SAR at which the above-mentioned changes in cells and

Table 1 Tissue dielectric properties for the human brain

Frequency (MHz)	Conductivity (ohm^{-1} m^{-1})	Mass density (kg/m^3)
900	0.7665	1,030.0
1,800	1.1531	1,030.0

Table 2 Some biological effects of radiowaves at different power density values

Power density (mW/m^2)	Reported biological effects
0.02	Sleep disorders, abnormal blood pressure, nervousness, weakness, fatigue, limb pain, joint pain, digestive problems, fewer school children promoted
0.6	Altered EEG; disturbed carbohydrate metabolism; enlarged adrenals; altered adrenal hormone levels; structural changes in liver, spleen, testes, and brain in white rats; and slowing of the heart in rabbits
1	Increase in melatonin in cows
1.3	Decreased cell growth (human epithelial amnion cells)
1.68	Irreversible sterility in mice
2.0–8.0	Childhood leukemia near transmitters
3	Impaired motor function, reaction time, memory, and attention of school children, and altered sex ratio of children
6	Change in calcium ion efflux from brain tissue, cardiac arrhythmias, and sometimes cardiac arrest (frogs)
10	Headache, dizziness, irritability, fatigue, weakness, insomnia, chest pain, difficulty breathing, indigestion (humans—occupational exposure), stimulation of white cells in guinea pigs
20	"Microwave hearing," clicking, buzzing, chirping, hissing or high-pitched tones
25	Breakdown of the blood–brain barrier
0–40	Altered white blood cell activity in school children

Table 3 SAR values estimated from Eq. 1 for 900 and 1,800 MHz

Site no.	SAR (900 MHz, %) over the ICNIRP limit of 2 W/kg	SAR (1,800 MHz, %) over ICNIRP limit of 2 W/kg
1	0.07	0.11
2	0.03	0.04
3	0.05	0.07
4	0.06	0.09
5	0.02	0.02
6	0.03	0.05
7	0.04	0.06
8	0.02	0.04
9	0.03	0.05
10	0.09	0.13
11	0.05	0.07
12	0.03	0.05
13	0.07	0.11
14	0.03	0.05
15	0.16	0.24
16	0.12	0.18
17	0.02	0.04
18	0.15	0.22
19	0.14	0.21
20	0.08	0.13
21	0.05	0.08
22	0.03	0.05

The recommended limit by ICNIRP for head is 2 W/kg. Table shows the percentage of SAR values (for head) calculated over ICNIRP limit for 900 and 1,800 MHz. The SAR is much lower than the ICNIRP limit, as can be seen from the table. However, it is much higher than the biological limit. The highest SAR was found to be 484% of the biological limit, for 1,800 GHz frequency, while the estimation of SAR values calculated using 900 MHz frequency gave this number at 322%.

tissue start taking place, 0.001 W/kg can be called the biological limit, above which SAR should be considered harmful. In the present work, the highest SAR was found to be 484% of the biological limit, for 1,800 GHz frequency, while the estimation of SAR values calculated using 900 MHz frequency gave this number at 322%. The recommended limit of SAR by ICNIRP for local area (head) is 2 W/kg which is far above the biological limit. The percentage values of estimated SAR (using Eq. 1) over the ICNIRP limits are mentioned in Table 3. It can be seen that highest SAR is only 0.24% of the ICNIRP limit for 1,800 MHz, as compared to 484% of the biological limit.

Similarly, the highest power density value obtained was 1,148% of the biological limit and the same value is only 0.26% and 0.13% of the ICNIRP limit for 900 and 1,800 MHz, respectively (Table 4). The highest power density value measured in a hospital was 7.7 mW/m^2, and from Table 2, it can be seen that

childhood leukemia has been reported in this range of exposure. The power density values of unsafe schools ranged from 1 to 11 mW/m^2 (Fig. 1). Health effects due to this exposure vary from decreased cell growth to cardiac arrest to stimulation of white cells (Table 2).

It was observed in the present studies that the schools and hospitals which were having higher values of radiation were within 400 m distance from the tower. However, the areas which are on the back side of the antenna gave lesser power values than the ones facing antenna even if they were within 400 m distance from the antenna. Hence, only being close to

Table 4 Measured power density values in terms of percentage of ICNIRP limit of 4.5 W/m^2 for 900 MHz and of 9 W/m^2 for 1,800 MHz

Site no.	Percentage of power density over the ICNIRP limit (900 MHz)	Percentage of power density over the ICNIRP limit (1,800 MHz)
1	0.11	0.06
2	0.04	0.02
3	0.07	0.04
4	0.1	0.05
5	0.02	0.01
6	0.05	0.02
7	0.06	0.03
8	0.04	0.19
9	0.05	0.03
10	0.14	0.07
11	0.08	0.04
12	0.05	0.02
13	0.12	0.06
14	0.06	0.03
15	0.26	0.13
16	0.19	0.09
17	0.04	0.02
18	0.23	0.12
19	0.22	0.11
20	0.14	0.07
21	0.08	0.04
22	0.05	0.02

The power density values were lower than the ICNIRP limit but higher than the biological limit. The highest power density value obtained is 1,148% of the biological limit, and the same value is only 0.26% and 0.13% of the ICNIRP limit for 900 and 1,800 MHz, respectively.

antenna does not make it as hazardous zone as being both close and facing it. Thus while doing such kinds of surveys, orientation of the antenna should be kept in mind. However, areas with group of towers have antennas facing in all the directions and overall power levels in such cases were high in any direction. The antennas were erected on the roofs of markets, and each market contained three to five towers. People working in the market, shopkeepers, office workers, students in nearby schools, and patients in the hospitals are spending many hours a day in these radiation hazard zones. Though the power density levels are lower than the one being recommended by the ICNIRP for the general public, but they are much above the levels at which the biological system starts

responding to the harmful radiation. The findings showing higher exposure levels in the evening hours compared to noon hours indicate more use of cell phones in the evening, making radiation density higher.

Conclusion

A measurement on electromagnetic radiation was conducted at 62 locations near schools and hospitals in Chandigarh city, India. The measured power densities and estimated SAR values were compared with international recommendations by ICNIRP for safety guidelines and with biological limits at which the actual adverse effects start. The results indicate that the average measured power density values are 419% higher than the biological limit and lower by 0.1% of the ICNIRP limit for 900 MHz and 0.06% for 1,800 MHz. This work is an initial effort to find the radiation exposure levels in our cities, but more detailed analysis needs to be done in the follow-up studies. Estimation of parameters like power density, current density, and SAR is important to know the radiation levels at far-field regions; however, electric and magnetic fields vary in rather complicated ways in the near-field region as the field structure becomes inhomogeneous. In that case, only power density is not an appropriate quantity to specify exposure and hence both electric and magnetic field strengths must be measured. Quantities useful to address perception and other indirect effects are contact current I_c and for pulsed fields, specific energy absorption SA, which should be considered for further studies on exposure levels. Also, parameters like effective isotropically radiated power or effective radiated power (ERP) will be useful to study in the follow-up investigation. These parameters can give real values of the power and field strength signal as they eliminate the losses and take into account the antenna gain for more accurate values. Height above average terrain cannot be ignored when calculating ERP as signal coverage dramatically increases with antenna height. Spectral content, spatial and temporal patterns, and polarization are some of the factors that may be considered for evaluating the biological effect. Estimation of all these parameters in future studies will give a clearer picture of the exposure of the general public to electromagnetic radiation.

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